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Object recognition with a smart low-cost active infrared sensor array

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Abstract

The paper presents an effective solution for determining characteristic features of objects from a simple measurement set-up. A low-cost IR diode array, working on a reflection light scanner principle, has been designed. Essentially arrays of several emitter-receiver pairs are mounted on different sides of the area of observation, enabling the estimation of the size of the object in different dimensions and its reflection coefficient. The emitters are driven successively in time, hence no signal overlapping and cross-talk occur. The results show that from simple light intensity measurements, a variety of objects can be reliably recognised. As an example, the problem of determining the number of people getting into or out of a room is addressed. Two arrays of 3 diode pairs each are mounted on both sides of a doorway. With the proposed sensor, people can be recognised easily and are well separable from other echoes (motion of hands etc.), making the performance far more reliable than that of ordinary light barriers.

Keywords: active IR array, echo feature extraction, object classification, people counting system

1 Introduction

Object recognition is important for intelligent systems that need to interact with and autonomously operate in their environment. Often it is required to recognise and to count objects moving across an inspection area. For presence detection and counting systems, numerous technical solutions based on a large variety of physical phenomena are available and still refined. However, for many applications it is desired to characterise an detected object (size, location, material, velocity of motion etc.) with a simple and low-cost sensor. Often it is difficult to distinguish between objects which partly cover.

For proximity sensing, position control and the recognition of target primitives, low-cost infrared sensors [1] can be used. Simple range estimates, however, are not sufficient, because the return signal intensity depends on both the geometry and the surface properties of the target. In [2], a number of commercially available infrared sensors based on position sensitive detectors (PSD) like the popular Sharp GP2D02 distance measuring sensor are evaluated. However, these devices are not specifically low-cost and, esp. the Sharp sensor, far too slow for our purpose. Moreover, from single intensity measurements it is not possible to deduce the geometry and surface properties of the target without knowing its distance and angular location. Mechanical scanning devices [3] are too sophisticated for many applications.

An example focused on here is the reliable counting of people getting into or out of a room. Contrary to common impression, this is not at all a simple task. As the experience shows, commonly used double-beam light barriers do not perform very reliably (see Section 5). Especially for applications where the correct number of persons in the room is important for an optimal performance (like e.g. occupancy-driven heating and ventilation), also only incidental errors cumulated over time make such devices useless. Visual detection with cameras [4] is again often not appropriate.

In order to detect and classify objects in a are of observation (persons in a doorway in particular), it is proposed to mount small infrared (IR) diode arrays, working on a reflection light scanner principle, on both sides of such objects, see **Fig. 1**. Due to range information from different angles of observation, the ambiguity of light intensity contributions from the range of the object from the light source and its reflectivity can be solved. The recognition is then based on the exploitation of model assumptions and additional knowledge learned during operation. No moving parts are applied and all components are very tiny and cheap.

2 Infrared array

The optical system consists of *N* pairs of a highly directional IR emitter diode and a shielded sensitive phototransistor, located close to one another. Due to the face-to-face mounting, the maximum range R_{max} can be reduced to almost the half of typical door widths ($R_{\max} \approx 0.5\, m$), what is still challenging for the detection of some materials and dark colours. A high transmitter power is one of the key elements.

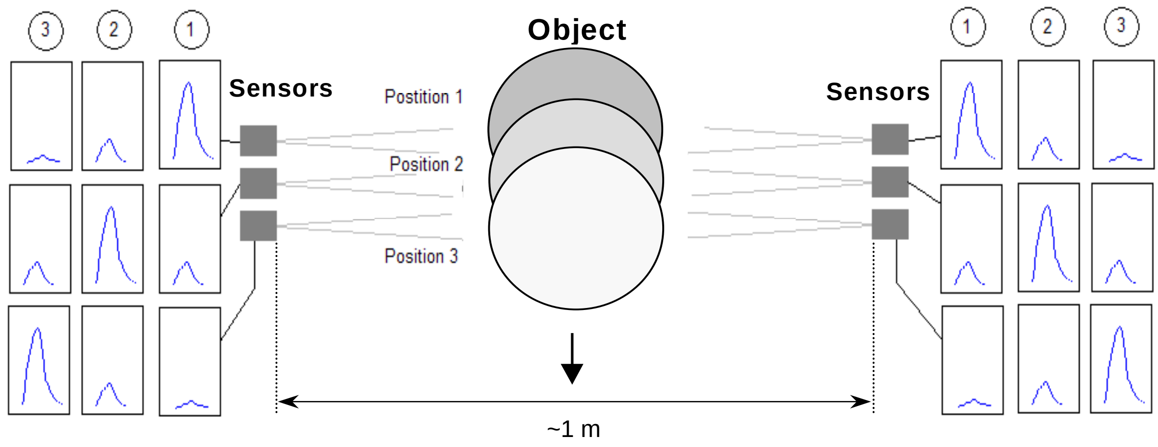

Fig. 1. *Basic configuration of the detector and amplitudes of the output signals for different object positions 1,2 3 (left and right columns), illustrating the working principle*

Pulsed NIR emitter diodes SFH 415-U diodes (Siemens, 930-970 nm) with a 12° 3dB beam angle and photo diodes TSL-252R (TAOS Corp.) with integrated preamplifier and a maximum sensitivity at approx. 950 nm have been chosen. The emitters are driven at temporally successive instances, hence overlapping and mutual influence of the echo signals is excluded. All received impulses are then demultiplexed into one channel. The processing is performed on a low-power 8 bit PIC micro-controller which generates the pulses, handles the timing of emission, determines and stores the received echo features and makes the decision about the object.

For the specific application as a people counter , two arrays will be mounted vertically on both sides of the doorway, containing each *N*=3 pairs of transmitter and receiver IR diodes (‘sensors’). Hence, the plain of observation will be horizontal. In order to gain a time dependency of the measured amplitudes in the direction of object motion, the pairs are inclined outwards, see **Fig. 2**. For a larger number of emitter-receiver pairs, even larger angles can be monitored and the resolution can be improved.

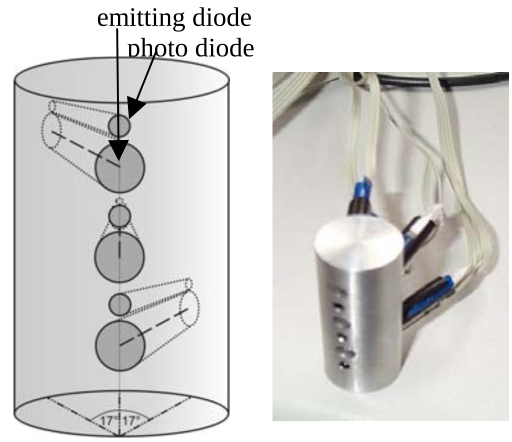

Fig. 2. *Emitter diodes and receiver photo diodes are paired and slightly inclined (~17°)*

In **Fig. 3**, the emitted and received pulses are shown for one (above) and all six sensors (below). The pulse length is 8 µs (charging the emitter diode to maximum). Due to receiver delays, the amplitude of the received pulse is detected approx. 1µs after the emitter pulse ends. The period between 2 emitting pulses is 36 µs.

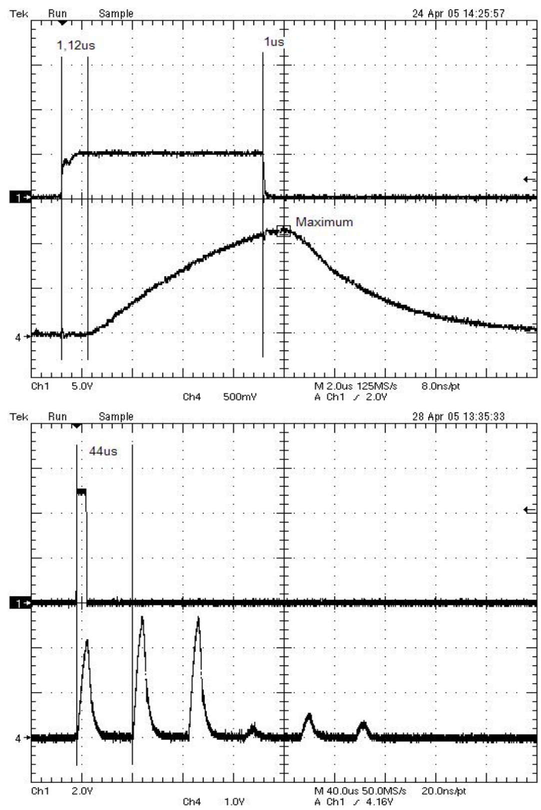

Fig. 3. *Transmitted pulse and received pulses for 1 sensor (above) and for 6 sensors (below). Sensors 1,2,3 receive a larger signal than sensors 4,5,6 because in this case the reflecting object is closer to them*

3 Object characterization

Light striking a surface of an object will be partly absorbed and reflected (diffuse reflection and specular reflection). The output signals of each sensor in the array depend on the distance and direction of the light source from the object, the intensity of source, surface characteristics of the object such as colour and reflectance properties as well as the location of the observer. Ideal diffuse reflectors reflect light according to *Lambert's cosine law* stating that the reflected energy from a small surface area in a particular direction is proportional to cosine of the angle between that direction and the surface normal:

$$I = I_p k_d \cos\vartheta \qquad (1)$$

with I_p - point light source intensity, k_d - surface reflection coefficient ($0 \le k_d \le 1$). Hence, the reflected intensity depends on the light source's orientation relative to the surface but is independent of the viewing direction, see Fig. 4.

A simple model for the illumination intensity I is then

$$I = I_a k_a + \frac{1}{d^n} I_p k_d \cos\vartheta \qquad (2)$$

where I_a - ambient light intensity, k_a - ambient light reflected, d - distance to the light source, n – loss factor, depending on the surface size and roughness: $n = 2..4$ (n=4 for a point reflector, n=2 for a large surface).

In **Fig. 4**, for a regular plain reflector the measured intensities are given as a function of the direction of the light source. The deviations from the intensities resulting from Lambert's law are mainly contributed to the reflection law.

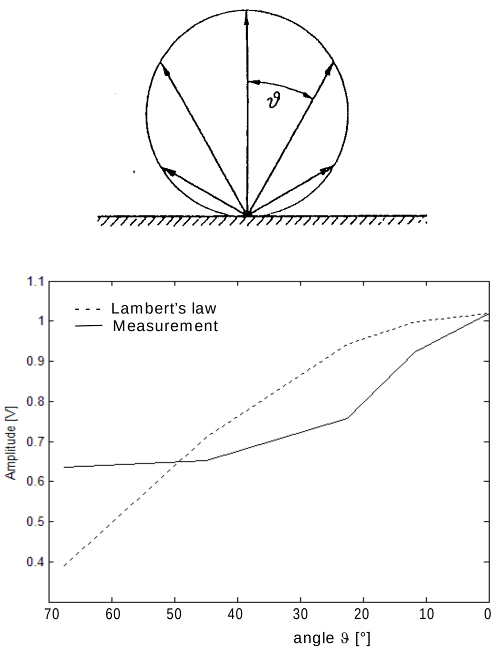

***Fig. 4**. Lambert's law, compared with measured intensities for different angles of the light source*

For each of the transmitter/receiver–pairs, the intensities of the received signals have been measured for a variety of materials with different colours and surfaces. In **Fig. 5** receiver pulse shapes and measured intensities as a function of distance are given for two materials: white (a) and black paper (b). Curves for materials with other colours are between these intensity curves.

Then, from the measured intensities, the object distance can be calculated. For this purpose, using the relation $I \sim \frac{1}{d^n}$, the observed behaviour has been modelled and the resulting sensor-specific distance functions

$$d_j = f^{-1}(I_j) \quad , j = 1..6 \qquad (3)$$

have been laid down in look-up tables for a fast processing in the micro-controller.

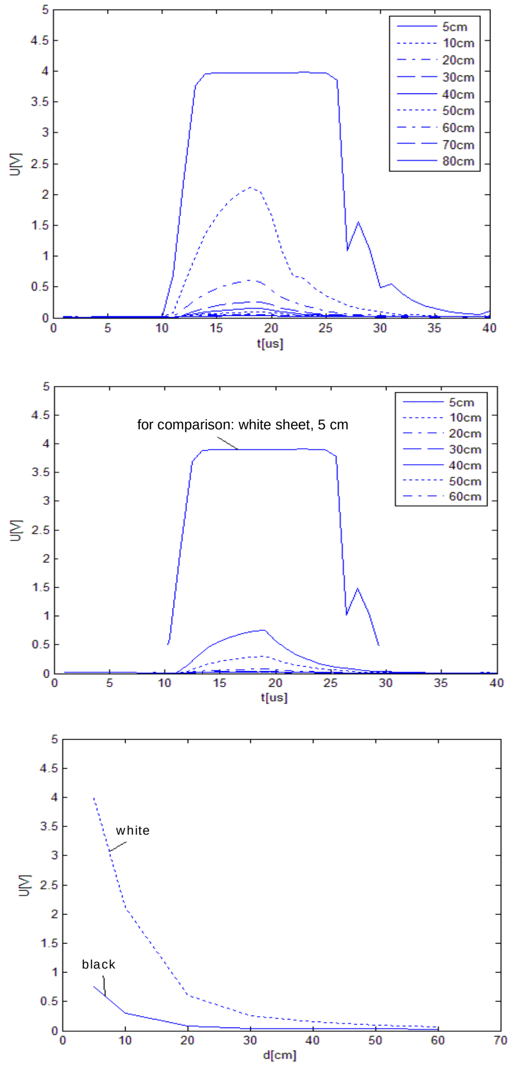

***Fig. 5.** Intensities and pulse shapes as a function of object distance from the light source for different materials (above: white sheet; below: black sheet)*

For a proper object recognition, several assumptions about the objects of interest should be made. For a person detector, such assumption will be that in the horizontal plain the object will be roughly a circle with a radius *R*.

In order to obtain the size and the reflection coefficient of an observed object, the received intensities I_j from all sensors *j* from the array can be modelled as

$$I_j = I_j(x, y, \overline{R}, k_d) \quad , \; j = 1..6 \tag{4}$$

with (x, y) - central point of the circle, $\overline{R}$ - mean radius.

Hence, from the 6 intensities $I_1,...,I_6$, a system of 6 equations is obtained, from which the unknown parameters *x*, *y*, $\overline{R}$ and k_d can be calculated. Later, an additional parameter, e.g. the form coefficient *a*, can also be determined from this set of equations. (For the regular circle, *a* is set to 1 for all sensors.) Hence, yet another property of the object can be deduced from the same measurements.

4 Experiments

For the purpose to assess the object recognition capability of the array, a PC-based processing has been set up (**Fig. 6**). The input signals from all 6 sensors are displayed (up left and right) and the object distances are calculated from maxima using the sensor-specific distance functions (3) (down right area in Fig. 6). Knowing the distance between all sensors in the array, the rough object size can be calculated and the object is shown in the center area. Objects can be displayed in real-time, giving a flexible observation tool.

For further illustration of the working principle, measurement of some more test objects are shown in **Fig. 7**. The 2 arrays of 3 sensors each are drawn on the upper and lower end of the diagrams. 3 successive time steps are shown, one in each row. In the left column, an object enters and leaves the area of observation between the 2 arrays, while in the right column an objects is located in different distances from the array.

5 Reliable people counter

The IR array has been used as a people counter at the entrance of a room. In **Fig. 8**, a set-up of two arrays (as shown in Fig. 2) mounted on both sides of the doorway is shown. Objects of interest (persons) are characterised by their size and counted, if the detected body size is in a pre-defined range and moves over a pre-defined time interval through all 3 barriers built up from the 3 opposite sensor pairs. Due to the inclination of the sensors towards one another, the body needs to move over a path length of approx. 0.5 meter between the 'leading' and 'closing' barrier in order to be detected as a person entering or leaving the room.

The performance of the proposed device has been compared with a reference sensor. A commercial IR double-light barrier (SICK W50) has been used at the same doorway. In **Fig. 9**, the readings of the two different detectors are compared and typical sources of false detection are demonstrated. While the commercial sensor can be easily fooled (it shows numerous missed and double countings, esp. when a person moves his/her arms or turns around in the doorway), the described simple IR array showed no false reading over a period of several days.

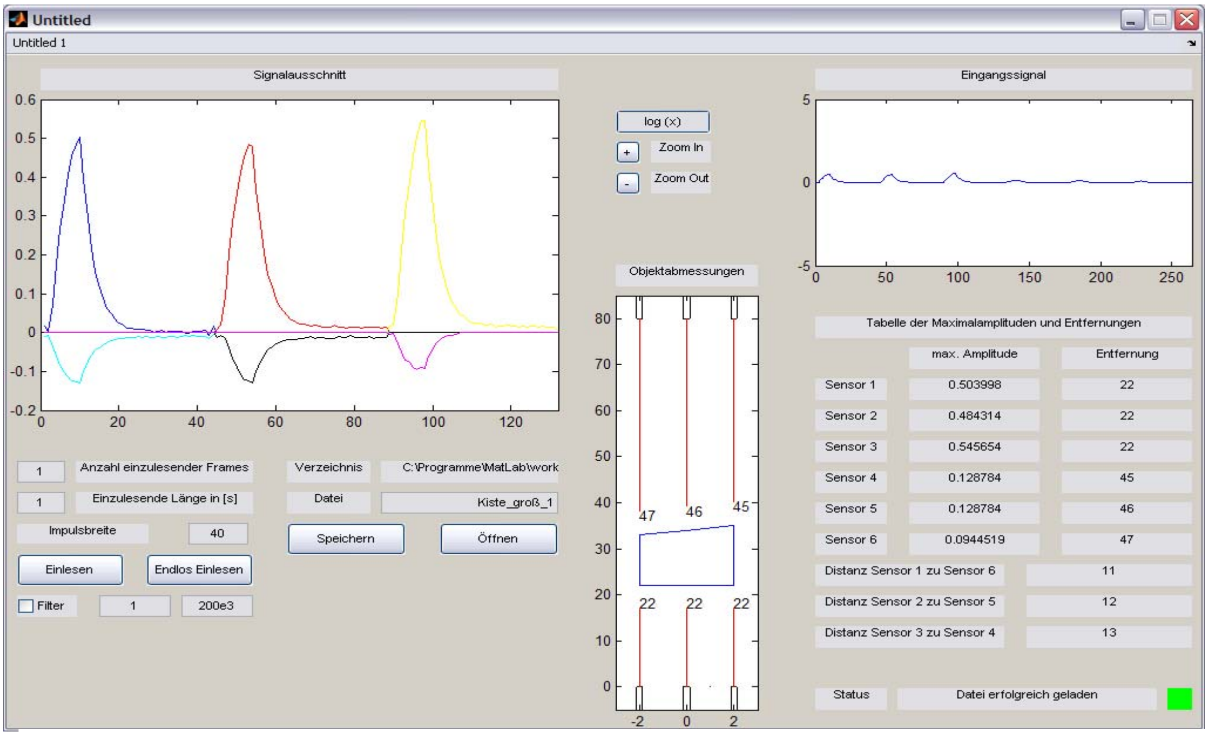

***Fig. 6.** User interface of the PC-based processing tool*

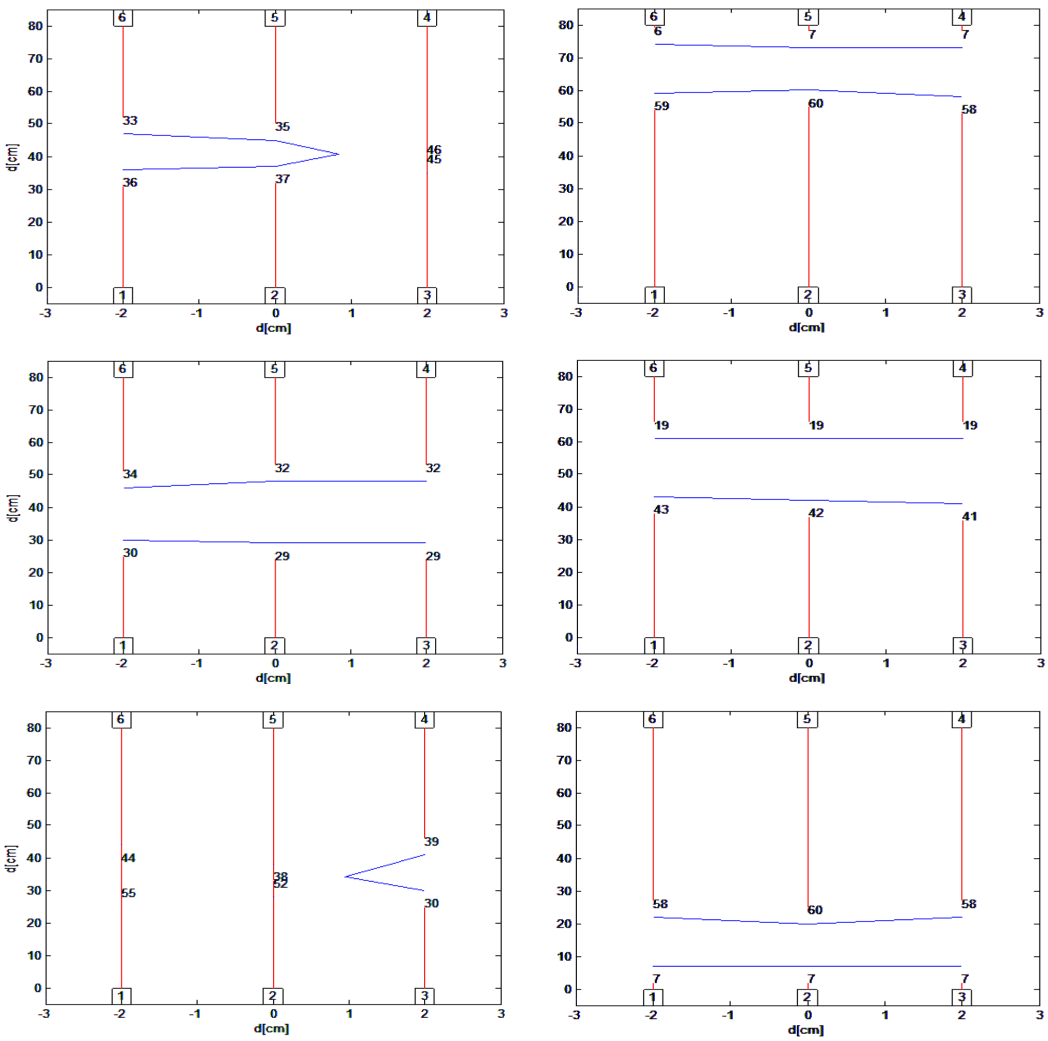

Fig. 7. *Measurement results: Recognition of object size and position in the area of observation from amplitude readings only*

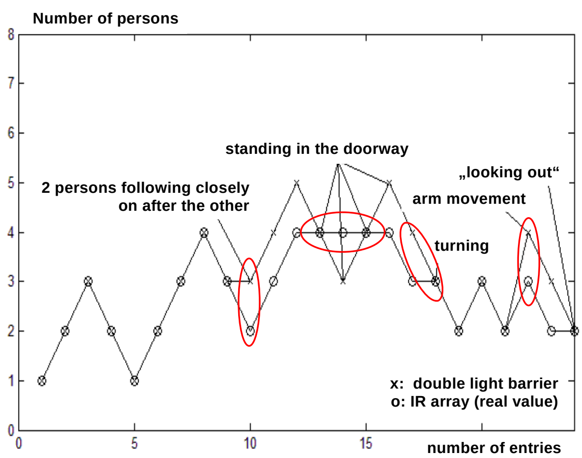

Fig. 8. *People counter: Arrays mounted at a door*

Fig. 9 *People counter: counting results compared with a commercial double-beam light barrier*

6 Conclusions

A solution has been presented for effective object recognition with a low-cost infrared array working on a reflection light scanner principle. Using model assumptions and gaining additional knowledge during operation, the size, reflectivity and position of objects can be deduced just from light intensities gained from a number of active IR sensors around the area of observation. As has been shown, the sensor can be successfully used to count the number of persons in a room. The performance is far better than that of commonly used light barriers. Several other applications of reliable object recognition, e.g. in robotics can be addressed. The described approach of referencing between the array nodes can also be used for self-monitoring of the sensor performance (e.g. detection of accuracy losses due to soiling etc.)

7 References

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